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ABSTRACT

Assuming spherical harmonics P_n^m as the eigenfunctions of the atmosphere dynamics above 200 km altitude, a transfer function $G_n = Q_n^m / \rho_n^m$ can be derived which gives the ratio between heat input component Q_n^m and the corresponding density component ρ_n^m in a development into series of spherical harmonics. G_n has the properties of a filter suppressing low periods (smaller than about 10 hours) and waves with small horizontal scales ($n > 2$). The implications of this filtering effect are discussed to show that it can explain a number of general properties in the thermosphere dynamics associated with tides, planetary waves and magnetic disturbances.

The objectives of this paper is to present a very simplified three-dimensional model. It was designed to aid in the interpretation of rather general phenomena in thermosphere dynamics such as the global nature of geomagnetic storm effects or the amplitude and time delay of the tidal and planetary variations. For that purpose it was desirable to have a quasianalytic model to enable the separation of the various energy components and their associated thermospheric structures. Therefore we started from the assumption that the following approximations be valid:

a) Perturbation approximation

b) Isothermal dissipative thermosphere

c) Spherical harmonics P_n^m as the eigenfunctions of the thermosphere.

These assumptions are fairly good approximations at thermospheric heights above 200 km. Non-linear effects in general do not dominate the thermosphere dynamics, the thermosphere is nearly isothermal above 200 km, and the thermospheric structure above this height justifies the spherical analysis.

This last point is illustrated in Figure 1, which gives the exospheric temperature distribution versus local time and versus latitude in terms of three spherical harmonics of lowest degree. This distribution which is valid during equinox approximates within 5% the exospheric temperature derived by Jacchia and Slowey [1] from satellite drag density data. In Figure 1 the dominant term is the term with $P_o^o = 1$ which describes the spatial and temporal average of the temperature. The term with $P_1^1 = \sin \vartheta$ (ϑ is the co-latitude) depends on local time and is responsible for the pressure and temperature bulge during the afternoon at the equator. It peaks at 15 hours local time. A less significant zonal term with P_2^o depending only on latitude is added which gives rise to a zonally averaged temperature gradient directed from the equator to the poles. Its existence can be explained as resulting from the mean surplus

of solar energy deposited at lower latitudes when compared with the energy input at higher latitudes. Several other quite interesting terms have been neglected for simplicity in Figure 1, e.g., a semidiurnal term which shifts the maximum of the pressure bulge from 15 hours to the observed 14 hours local time.

Local time dependent terms with wave domain numbers $m > o$ can be considered as tidal waves. The term with P_1^1 is the fundamental symmetric diurnal tidal wave mode. The other terms with number $m = o$ are called planetary wave modes.

Although Jacchia's exospheric temperature is only a measure for the observed density, Figure 1, nevertheless shows that the large scale features of thermosphere dynamics appear to be rather simple and can indeed be described in terms of few spherical harmonics of lowest degree (n,m).

It can be shown from an analysis of three-dimensional thermosphere dynamics that the spherical harmonics become, to a fair degree of accuracy [2], the eigenfunctions of the thermosphere above 200 km. If one assumes the heat input Q developed into a series of spherical harmonics and if one assumes a height profile of the coefficients Q_n^m in this series proportional to the mean pressure P_o, then one finds an assympotic relationship between the heat input coefficient Q_n^m and the corresponding density coefficient ρ_n^m.

$$\rho_n^m = G_n(\omega) \quad Q_n^m$$

The function $G_n(\omega)$, depending only on the zonal wave domain number in our simplified theory, is a function of the angular frequency ω of the respective wave. It can be considered as a system transfer function which essentially

represents the efficiency for the excitation of the density amplitudes by the respective heat input component.

Numerical calculations, using plausible data within the height range between about 300 and 400 km, were made to derive magnitude and phase of the transfer function G_n. It is shown in Figure 2 as function of frequency ω or of period t (the upper scale in Figure 2), with the parameter n being the zonal wave domain number.

From Figure 2a we notice a low pass filtering effect which is due to the long thermospheric response time. Waves with periods smaller than about 10 hours are suppressed except for large numbers n in a window near periods of about 3 hours which is just the range of internal gravity waves. This results from resonance effects within the thermospheric cavity.

A second filtering effect is apparent in connection with the increasing zonal wave domain number n. Since n is a measure for the meridional scale length of the respective spherical harmonics P_n^m, we can interpret this filtering effect as due to the increasing number of circulation cells of the wind field associated with the density distribution ρ_n^m. Both density ρ_n^m and the associated winds are generated by the heat input term Q_n^m. If the horizontal wind structure is simple or even non-existing as in the case of n = o, most of this heat input is transferred into internal energy of the gas, that means, into temperature and density amplitudes. With increasing number n, an increasing fraction of the energy is needed to drive the wind field, and a decreasing amount of heat input remains to increase the corresponding density amplitudes.

This can be seen most drastically in the case of zonal wave domain number n = o which describes the world-wide mean increase of the density. Here nearly the entire solar heat input is transferred into internal energy of the gas increasing in a most efficient way the density and temperature of planetary waves

with periods larger than about 1 day. However, in the case of n = 1 which includes the fundamental diurnal tidal wave of Figure 1, a significant fraction of the corresponding solar heat input component is transferred into kinetic energy to drive the Kohl-King-Geisler wind [3], [4] which reduces the available fraction of the heat input to increase the density. The same is true for the fundamental symmetric semidiurnal wave with wave domain numbers (2,2). Although the corresponding solar heat input coefficient Q_2^2 is about half the value of the fundamental diurnal component Q_1^1, the filtering effect of the thermosphere furthermore reduces the density amplitude by a factor of about 3, so that the ratio between diurnal and semidiurnal density component is about 6 : 1 in rough agreement with the observations.

From Figure 2b we note a time delay of 3 hours in the case of the diurnal wave p_1^1 and a delay of 1 hour in the case of the semidiurnal wave, both in agreement with Jacchia's observations [1].

Figure 2a and 2b allow also to explain the results of the Harris-Priester model [5] and the meaning of the second heat source. Harris and Priester, using a one-dimensional model, treated the ρ_o^o - component with a period of one solar day. According to Figure 2, this leads to a large density amplitude and a time delay of about 6 hours. However, the correct density component of the diurnal tide is the ρ_1^1 which has the right amplitude and phase in agreement with the observations. The second heat source of Harris and Priester was therefore an ingenious trick to simulate the effect of the kinetic energy in the (1,1) component.

Moreover, this simple model can describe general features of the geomagnetic activity effect [6]. During a geomagnetic storm, energy stored within the magnetosphere is deposited within a small strip within the auroral ovals in the night time hemisphere. If the geomagnetic storm is of the substorm type with a duration of a few hours, it generates predominantly short periodic gravity

waves and does not affect significantly the large scale density features. If, however, a big storm occurs with an impulse width of about one day, then a sufficient fraction of its spectral energy is transferred into the ρ°_o - components of the density. The time response of the ρ°_2 decreases to 1 hour. The sum of the ρ°_o - and the ρ°_2 - component gives then a larger density amplitude and a smaller time delay at the poles than at the equator which is in general agreement with the observations [7], [8].

It is obvious that such a simplified model as presented here cannot describe details of the thermosphere dynamics, and it cannot replace in any way empirical models like the Jacchia-model [9]. However, it seems to be helpful in the understanding of rather fundamental dynamic properties of the thermosphere in which temporal and spatial distributions of heat sources are involved.

LITERATURE

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EXOSPHERIC TEMPERATURE DISTRIBUTION (in °K)

$$T(\phi,\tau) = 1130^\circ P_0^0 - 10^\circ P_2^0(\phi) + 130^\circ P_1^1(\phi) \cos\left[\Omega(\tau - 15^{00}h)\right]$$

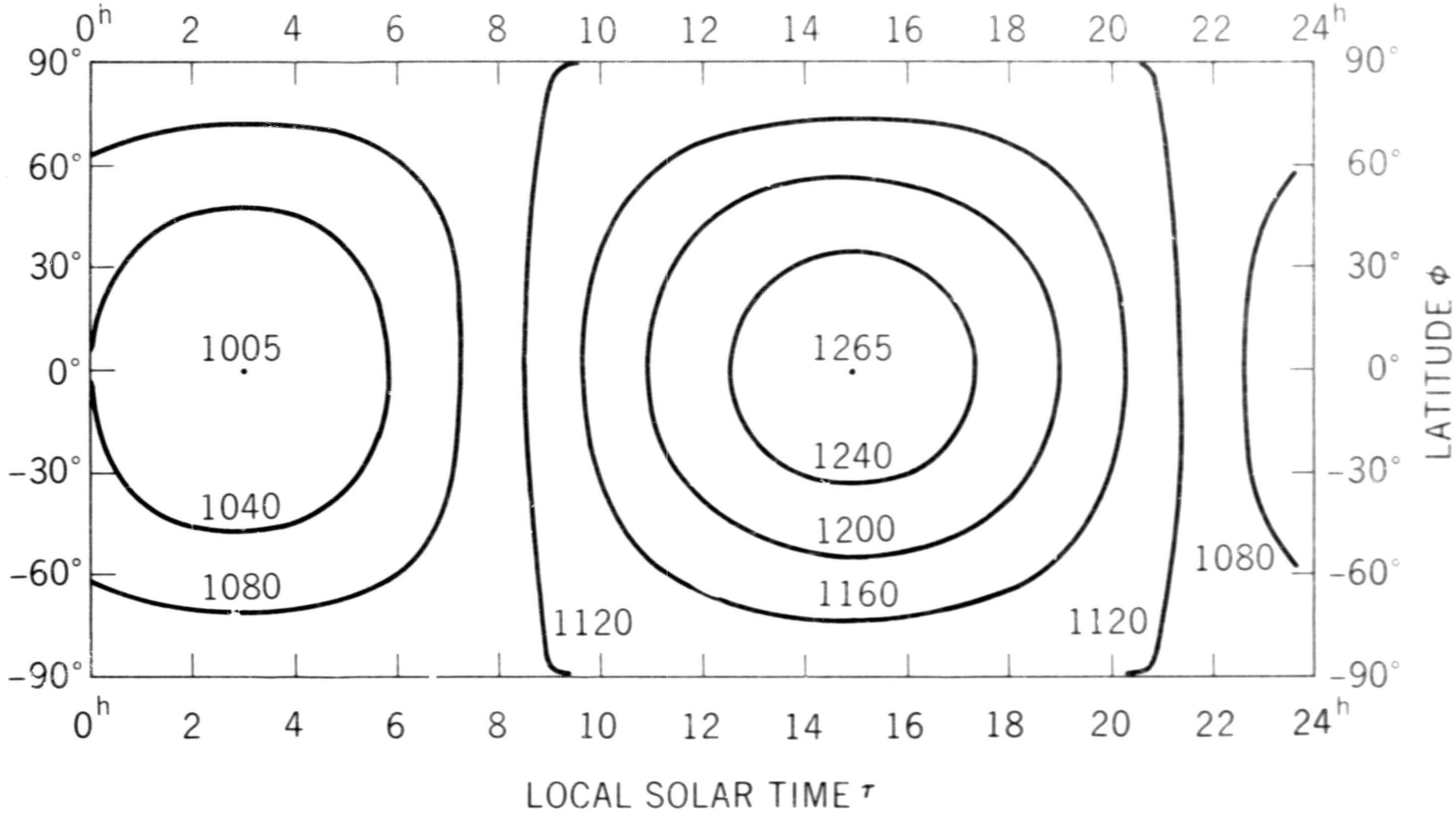

Figure 1. Exospheric Temperature distribution according to Jacchia and Slowey [1] approximated by three spherical harmonics.

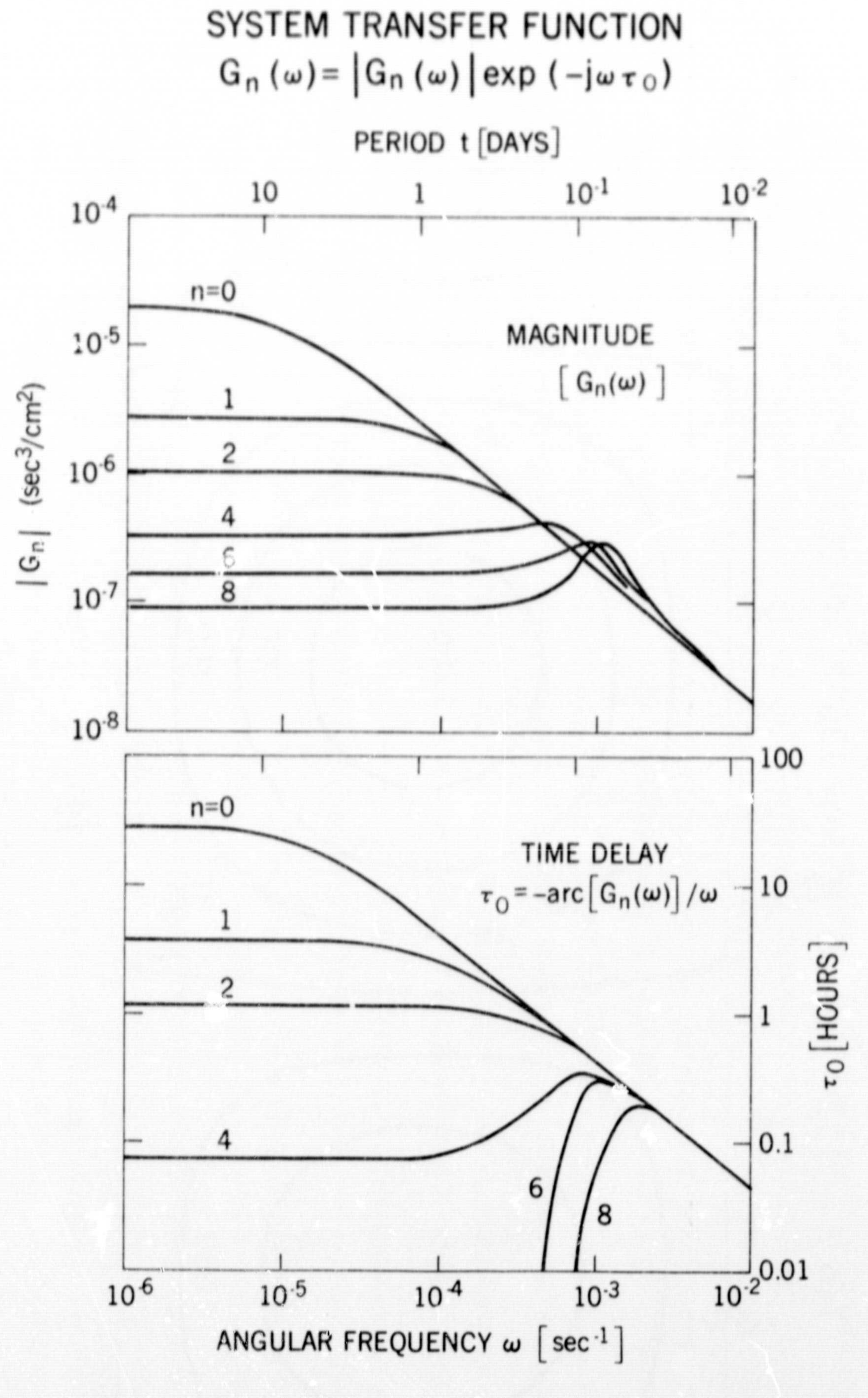

Figure 2. Magnitude (Figure 2a) and phase (Figure 2b) of the system transfer function $G_n(\omega)$ versus angular frequency ω. Parameter is the zonal wave domain number n. The time delay has been determined from the phase by the relation $\tau_o = \phi/\omega$.